§7. Study of Ambipolar Radial Electric Field in High Electron Temperature Plasmas in LHD

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The Large Helical Device (LHD) [1] is a heliotron device (poloidal period number L=2, and toroidal period number M=10). The radial electric field (E_r) is derived from the poloidal and toroidal rotation velocity and pressure gradient for neon impurity measured with charge exchange spectroscopy [2] at the vertically elongated cross section.

A high central electron temperature (exceeding 10 keV) has been achieved by highly local ECH using a strongly focused Gaussian beam at the fundamental and second harmonic resonance [10]. The magnetic field strength and the configuration are selected to have a power deposition as nearly on axis as possible. The expected power deposition profile estimated by ray tracing, including the weakly relativistic effect, indicates that almost all of the injected power (about 1.2 MW) are concentrated within an average minor radius of $\rho \leq 0.2$. The electron temperature profiles are measured with the high power YAG-Thomson scattering system [12]. The profile is already sharp in the phase where only the 84 GHz power injected and the 82.7 GHz power assists to raise the central electron temperature more than 10 keV (cf., Fig. 2 in Ref. [10]). These high electron temperature modes appear only when the injected power exceeds a certain threshold level, and this threshold level increase with the electron density. The dependence of T_e on the averaged density is considered from the viewpoint of neoclassical ambipolar E_r. The central T_e is abruptly increased when the ECH injection power exceeds a threshold value, which increases with the density (cf., Fig.1(b) in Ref. [12]). Here, this density dependence of ECH threshold power is also considered from the viewpoint of neoclassical ambipolar E_r on the (n_e, T_e) plane. The $T_e(0)$ is plotted as a function of the density as shown in Fig. 1. The calculations of ambipolar E_r is performed at ρ=0.2. The $T_e(0)$ in deduced from T_e at ρ=0.2 with assuming the parabolic profile, $T_e \propto (1-\rho^2)$. The n_e is almost the same between ρ=0 and ρ=0.2 since the density profile is assumed as $n_e \propto (1-\rho^8)$, which is a typical density profile in LHD. The plotted boundary is for a case with T_e/T_i=2 with $T_{e,i} \propto (1-\rho^2)$. This condition corresponds to the case before the steep gradient of T_e appears since the central ion temperature, $T_i(0)$, is measured as $T_i(0) \approx 1$ keV by crystal spectrometer [13] and, on the other hand, $T_e(0) \approx 2$ keV. The experimental results are also shown in Fig. 1 for reference (red for a case with $n_e = 0.3 \times 10^{19} m^{-3}$ and blue for $n_e = 0.5 \times 10^{19} m^{-3}$). The $T_e(0)$ abruptly increases when $T_e(0)$ reaches a threshold (corresponding to the boundary between E_r<0 and E_r>0). It is also recognized that the temperature threshold, $T_{e,th}$ increases as n_e is increased, which seems to be consistent with the theoretical prediction of $T_{e,th} \propto n_e^{0.4}$ [14]. It looks that the abrupt increase of T_e occurs just after entering Er>0 regime. More detailed neoclassical calculations and more experimental data (especially close to the threshold) would be required.

In conclusion, The high T_e has been obtained with a center-focused ECH. There is a threshold for the ECH power to achieve steep gradient of electron temperature, which also seems to be qualitatively consistent with the transition of ambipolar E_r in the sense that, at least, significant increase of T_e occurs after entering the anticipated positive E_r regime.

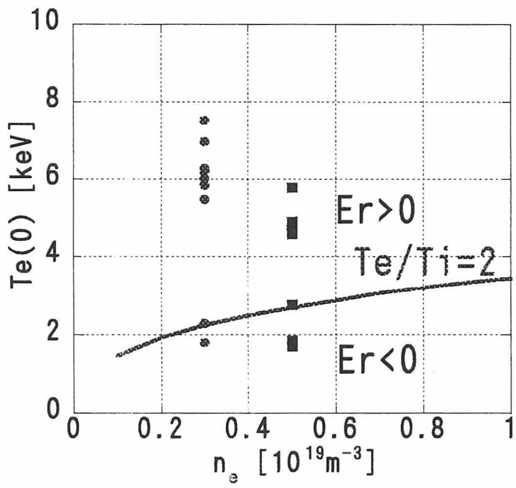

Fig. 1: The classification of the sign of ambipolar E_r on the (n_e, T_e) plane. The boundary is for the case with T_e/T_i=2 with $T_{e,i} \propto (1-\rho^2)$. For reference, experimental data points shown in Fig. 1 in Ref. [12] are also plotted (red for a case with $n_e = 0.3 \times 10^{19} m^{-3}$ and blue for $n_e = 0.5 \times 10^{19} m^{-3}$).

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